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Chapter 6

Installation and Construction

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INSTALLATION AND CONSTRUCTION

This chapter provides information on the handling and installation of corrugated polyethylene pipe and fittings in non-pressure applications including most sewers, culverts and subdrainage systems. All types of pipe, regardless of material, must be installed as specified to perform as expected.

The Department of Labor, Occupational Safety and Health Administration (OSHA), Safety and Health Regulations for Construction requires observance of its safety and other guidelines during all phases of construction including foundation preparation, excavation, pipe handling, assembly and backfilling. Stricter requirements may be required in some states and local jurisdictions.

Additional guidelines for the installation of corrugated polyethylene pipe are located in the following standards:

- ASTM D 2321 – Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications
- CAN/CSA B182.11 – Recommended Practice for the Installation of Thermoplastic Drain, Storm and Sewer Pipe and Fittings
- AASHTO Section 30 – Thermoplastic Pipe

Importance of Good Installation Practice

The structural design of a buried pipeline presumes the response to loads of a pipe/soil composite structure. Attention to detail on the part of the contractor, transporter and yard handler is essential to insure proper performance. Proper dimensional controls of trench excavation, pipe laying and pipe joining are essential to the success of a project. Correct selection and compaction of the soils composing the pipe/soil envelope are likely to dominate the structural performance of both pipe and soil. The desired constant pressure around the pipe and uniform support of the pipe in the longitudinal direction cannot be achieved in the absence of good practice.

ASTM D 2321, AASHTO Section 30 and CAN/CSA B182.11 define good practices for the installation of thermoplastic pipe. Each recommends proper techniques for trench excavation, placement, bedding and backfill to assure the pipe performs well during its full service life. AASHTO Section 30 is narrowly focused on gravity flow highway and airport drainage pipelines under pavements subjected to heavy wheel loads. Shallow burial is a major consideration. ASTM D 2321 is broadly focused on the general class of gravity flow pipelines, which include both drainage and sanitary facilities. Non-trivial differences exist between the two specifications. Federal, state, county and city governments, or other agencies or organizations of jurisdiction, are

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responsible for setting the particular governing standards appropriate to the installation of interest. References to specifications in this chapter are not intended for use in all pipelines at all locations; they are intended only to serve as examples of good practices.

Transportation, Handling and Storage

The contractor should conduct an inspection at the time of delivery to verify that the correct products and the expected quantities are received. Pipe walls and corrugations, gaskets, pipe ends, couplers or other joints, and accessories should be visually inspected for damage such as cuts, gouges, delamination, bulges, flat areas and ovality that may have occurred during shipment. Nominal pipe size, manufacturer's name, date code and applicable standards generally are marked on the pipe.

To prevent injury to construction personnel and damage to pipes, dropping and/or rolling of pipes during unloading and handling should be prevented. Refer to the manufacturer's instructions for unloading of trucks, trailers and railcar platforms. Pipes 18 in. (450 mm) or less may be hand lifted and placed by two people. Larger sizes require mechanical equipment; a minimum of two lifting slings of fabric or plastic, located at third points along the length, is preferred. (Metal chains and cables are to be avoided.) Equipment such as loading booms or forklifts should not be used since they can damage the pipe. Pipe should never be dropped on the ground.

Palletized pipe should remain on pallets for jobsite storage. Non-palletized pipe should be stockpiled for temporary storage in a flat debris-free area clear of construction traffic. Do not remove tie-down straps or bands until the pipes have been secured.

Pipes should be stockpiled on level ground and restricted to a stack height no greater than 6 ft. (2 m). To prevent rolling, blocking should be provided at approximately third points along the length. The removal of any one pipe should not cause shifting or rolling of any of the remaining pipes. The pipe should be supported along its length, avoiding concentrated loads along bell ends. Any protective covering of gaskets should remain until the pipe is ready for installation; exposed gaskets should be protected from dust and exposure to sunlight. Couplers and fittings should be stored flat to prevent distortion and damage. For pipe with attached bells, a common stacking method is to alternate the direction of the pipe lengths so that the bells are not stacked on each other. For smooth interior pipe, nesting smaller pipes inside larger pipes can minimize the storage space. Factory installed gaskets on the spigot may be protected by positioning them between pipe corrugations. Nesting corrugated interior pipe should only be done when the pipe can be easily removed. Extreme summer heat could affect the ovality or shape of some pipes. It is recommended that products be rotated during storage to eliminate such deflection.

Trench Excavation

The soil envelope of a pipe/soil composite structure will reflect the qualities of the native materials beyond the trench walls containing the pipe. If the soil stiffness beyond the trench wall is stiffer than the expected stiffness of the compacted trench fill, then the specified trench width is generally governed by that width necessary to insure the prescribed compaction. For competent in-situ soil, wider than necessary trench widths are not advised. Should the soil stiffness beyond the trench wall be less stiff and/or readily more compressible than the required trench fill, then the trench width is often specified by the customer agency or organization to be wider than usual (see ASTM D 2321). Success of the design of the installation depends, in part, upon realization of the geotechnical information describing the in-situ soil properties. If, during the course of excavation, the soils or soil properties are not what were expected as noted in the contract, the organization responsible for design should be informed. See Figure 6-1 for definitions of trench terms.

Figure 6-1

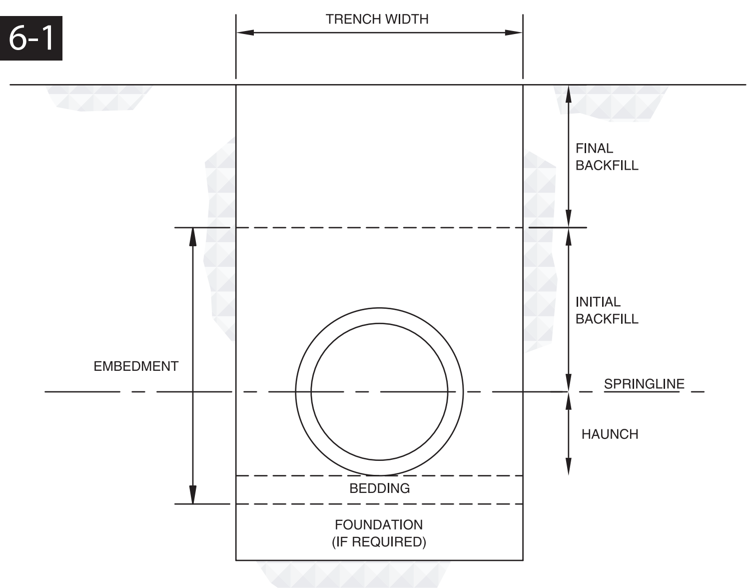

Figure 6-1: Trench Terms

In the absence of unusual conditions, and for purposes of guidance, the provisions of ASTM D 2321 and CAN/CSA B182.11 are noted. According to ASTM D 2321, the trench width should be no wider than what is required to safely and conveniently compact backfill material on either side of the pipe. Trench widths will reflect the selection of backfill material, ease of compacting backfill in the haunch zone (from pipe bottom to springline), compaction methods, pipe diameters and the width of the nearest larger size excavator bucket (for pipes of diameter 10 in. (250 mm) and smaller). In unsupported unstable soils, knowledge of the depth of cover, the stiffnesses of backfill and in-situ soils, and the size of the pipe are required for a determination of the trench width by the responsible engineer. AASHTO Section 30 requires a minimum trench width of not less than 1.5 times the pipe outside diameter plus 12 in. (300 mm). ASTM D 2321 establishes trench widths as the greater of either the pipe outside diameter plus 16 in. (400 mm) or 1.25 times the pipe outside diameter plus 12 in. (300 mm). See Table 6-1.

Table 6-1

Minimum Trench Width[1]

Inside diameter in. (mm)	Typical Outside Diameter in. (mm)	AASHTO Sec 30 Min. Trench Width in. (mm)	ASTM D 2321 Min. Trench Width in.(mm)
4 (100)	5 (120)	19 (480)	21 (530)
6 (150)	7 (177)	22 (570)	23 (580)
8 (200)	9 (233)	26 (650)	25 (640)
10 (250)	11 (287)	29 (740)	27 (690)
12 (300)	14 (356)	33 (840)	30 (760)
15 (375)	18 (450)	39 (980)	34 (870)
18 (450)	21 (536)	44 (1110)	38 (970)
21 (525)	24 (622)	49 (1240)	43 (1080)
24 (600)	27 (699)	53 (1350)	46 (1180)
30 (750)	34 (866)	63 (1600)	55 (1390)
36 (900)	41 (1041)	73 (1870)	63 (1610)
42 (1050)	48 (1219)	84 (2130)	72 (1830)
48 (1200)	54 (1372)	93 (2360)	80 (2020)
54 (1350)	61 (1577)	105 (2670)	90 (2276)
60 (1500)	67 (1707)	113 (2870)	96 (2440)
72 (1800)	80 (2032)	132 (3350)	112 (2840)

[1] Also refer to manufacturer's recommendations

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For two, or more, parallel pipes in a common trench, properly compacted backfill is required between pipes. Minimum spacing between pipes may be satisfied by the following (see Table 6-2):

Table 6-2

Minimum Spacing of Parallel Pipes in a Single Trench

Normal Diameter (D) in. (mm)	Minimum Spacing in. (mm)
≤ 24 (600)	12 (300)
> 24 (600)	D/2

Depending on the type of backfill, the compaction equipment and joining methods, these dimensions may need to be increased.

Stable sidewalls are a requirement for all trench construction. Proper slopes for unbraced walls or appropriate bracing and shoring with sheeting or shields for vertical walls are required. As sheeting and shoring are removed, compaction of material in the void space must proceed with the removal of supports. Geotextiles, or filter fabrics, may be considered in areas where the native soil is very soft and/or migrates easily. Geotextiles designed for strength and stability may help overcome some of the structural deficiencies in soft native soils and allow reductions in trench widths. They may also be placed on the trench bottom and sides to separate native soils and backfill material. All trenches should be backfilled as soon as practicable, but not later than the end of each working day. Also, care should be taken to protect excavated soil from collecting moisture while the trench is prepared and pipe is laid.

Uniformity of the underlying soil that forms the trench bottom will avoid stress concentrations and associated irregular pipe deformations. The condition of short reaches of non-uniform in-situ soils may be remedied by compacting and leveling the native soils. Alternatively, for the full width of the trench, the trench bottom may be over-excavated, often to a minimum depth of 6 in. (150 mm), and replaced with a layer of properly compacted (as specified) imported material. This same alternative is appropriate for the condition of a trench bottom that initially includes the occurrence of large protruding boulders. Where pipe segments are joined with protruding features, such as the bells of bell and spigot joints, recesses constructed in the trench bottom, followed by hand compaction of backfill around the joint, will provide continuous support and uniform bearing.

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Differential settlements may compromise the structural integrity of a buried pipe. Trench bottoms should be free of large stones, clumps of soil, frozen soil and debris; they should be slightly over excavated to allow for bedding material. If trench bottoms have less than ideal soil conditions, the preferred method is to remove the poor soil and replace it with soil that will provide predicable behavior. If replacement of the soil is not possible, long reaches of soft-to-hard trench bottoms may be managed with a minimum of two short lengths of pipe with gasket joints that will accommodate the tendency of longitudinal pipe rotation in the transition zone. The use of long lengths of pipe across the transition zone carries the risk of a pipe's joints opening, or cross-sectional distortion in response to unavoidable rotation.

If unexpected deposits of soil that, when wetted, will settle rapidly (dry silts and sands of low density) or swell (expansive clays) are encountered, the contractor is advised to contact the agency of jurisdiction for preferred strategies addressing anticipated problems. Alternatives may include removing the offending material followed by recompaction of the original or higher quality soil, chemical stabilization of the in-situ soil, and/or various schemes for protecting against the accumulation of water in the sensitive regions.

Dry trench conditions are a prerequisite for proper placement and embedment of drainage pipe. Surface water draining towards the trench must be redirected. Water in the trench during pipe installation can create a safety hazard. Maintenance of line and grade is more difficult with a tendency for pipe flotation. Dewatering is required to minimize these disabilities and the likelihood of instability of trench walls and slopes. Ground water should not be permitted to rise above the trench bottom until after the installed pipe is fully bedded and enough fill is in place to prevent flotation. When well points are used to lower the ground water, adjacent areas and structures must be monitored to prevent damaging subsidence. Sheeting and shoring for vertical trench walls should not permit the seepage of water and soil in areas where groundwater is higher than the trench bottom. Any loss of fines due to seepage or dewatering is evidence that soil voids in the vicinity of the pipe are being created. To limit this type of damage to the pipe/soil composite structure, dewatering operations must be monitored for the presence of a significant loss of fines.

Laying and Joining of HDPE Pipes

Pipe sections should be lowered into the trench without damage to the pipe or pipe ends where couplings are to be made. Field cuts may be made with a handsaw or power pipe cutoff saw. For pipes of annular corrugations, square cut only through a corrugation valley, never through a corrugation sidewall. Spirally corrugated pipe should be cut with a cutting guide (a standard coupling is useful) or reference marks

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around the circumference. Where skew or bevel cut ends are required, they should be properly reinforced with concrete slope-collars, headwalls or mortared riprap, as is appropriate. When the assembling of pipes is interrupted, closures should be placed at ends of pipes to prevent the introduction of dirt, water, animals and other foreign matter.

Unless otherwise specified, all joints of all drainage pipes are generally required to be soil tight. Joints that will permit the transport of soil at any time during its service life must be expected to cause problems related to erosion of invert and springline support. The integrity of the pipe/soil composite structure risks being severely compromised. Split couplings are often used for soil tight joints; they cannot be used for watertight joints. Gasketed joints (or welded joints) are often used when water tightness is required. Gasketed joints are flexible joints, which are of value in effecting long-radius horizontal and vertical curves without the use of special fittings or skewed cuts. During handling, placement and joining, bell and spigot joints, other gasketed joints, and gaskets must be free of mud, grit and other foreign material in order to enable effective joining and sealing. All manufacturers provide instructions for lubricant type and manner of application to the gasket, and/or the surface in contact with the gasket. Each gasketed joint should be inspected for cleanliness and proper lubrication before mating; a dry unlubricated spot is a source for a leak.

After the joint is aligned, it is necessary to drive the spigot end of one pipe its proper distance into the receiving bell of an adjoining pipe. Pipe should be laid with bells upstream. A bar and block (to protect the bell end) may be used to provide the levered action. This consists of a vertical bar driven into the ground (the fulcrum), bearing against a horizontal wood block that protects the upstream end of the pipe to be moved. Alternatively, mechanical equipment may be used to provide the necessary force. Avoid sudden thrusts of force, which can damage the pipe. The gasket must always remain in its intended groove.

At laterals, catch basins and manholes, attention to proper fit and alignment is required. All pipe manufacturers are prepared to supply tees, wyes, elbows, end caps and other styles of fittings. The design engineer and/or the pipe manufacturer, not the contractor, are usually responsible for connection detail design.

Taps – connections coming into the pipe perpendicular to its axis – may also be needed to connect a downspout or similar small diameter pipe to the storm sewer. For systems not required to be watertight, options include using a fitting designed for such an application. Watertight systems may require additional fittings or adapters. The pipe manufacturer's instructions for insertion and sealing should govern for each pipe size and profile of his/her inventory.

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It is not unusual for corrugated polyethylene pipe to be connected to other types of pipe materials. Available options depend on the joint quality required throughout the system and the particular combination of pipe materials. In most storm sewer applications, the pipe can be joined by butting the pipe ends together, wrapping them with a geotextile, and pouring a concrete collar around them. Although such a connection is dependent on contractor expertise, it will generally limit soil intrusion but not provide a watertight joint. Watertight connections between different materials will require additional fittings and adapters. If those options are not acceptable, a manhole should be used to make the transition.

Manholes facilitate changes in pipe size, grade or direction, and cleanout access. Catch basins serve as inlets for surface storm water drainage and cleanout access. Precast concret manholes and catch basins are manufactured with openings for standard inlet or outlet connections. Usually, the drainage pipe is inserted into a prepared hole slightly oversized to receive a standard size pipe. When a hole must be cut in the concrete, it should be only slightly larger than the pipe it receives. Grouting of the remaining void space secures and seals the connection; non-shrink grout is an option. Manufacturers have other pipe-to-manhole connectors from HDPE to concrete, such as rubber "boots", that provide either water or soil tight performance, depending on the needs of the system.

Special care should be taken when preparing the foundation for manholes, catch basins and the drainage pipes that connect to them. To preclude the possibility of significant differential settlements, compaction of the supporting soil should be firm for both pipe and structure. If the manhole should settle more than the pipe in the trench, the pipe would be forced to assist in the support of the manhole – a possibility not anticipated by the design. Shorter lengths of pipe with end connections that will allow for even minor rotation will benefit the structural performance and improve the efficiency of pipe-to-structure seals. Special care should also be taken with respect to any previously installed pipes, fittings, etc. that may become part of the new system.

Bedding, Haunching, Initial Backfill and Final Backfill

Uniformity of support and proper alignment of the pipe require a trench bottom of stable soils and free of protruding rocks. Good practice often requires over-excavation and replacement of the foundation material with a suitably-graded soil mixture to inhibit migration of fines and subsequent loss of pipe support.

Embedment materials are those used for bedding, haunching and initial backfill (See Figure 6-1). Very often compaction of fill soils in the foundation, bedding, haunch and initial backfill zones is limited to 6 in. (150 mm) layers (after compaction). AASHTO Section 30 requires a minimum of 8 in. (200 mm) layers before compaction.

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Controlled low strength mortar (CLSM) and controlled density fill (CDF) are flowable fills which – with restraints to prevent pipe flotation – may be used for backfill and bedding. With CLSM backfill, AASHTO Section 30 permits a reduction in trench width to a minimum of the outside diameter plus 12 in. (300 mm). When CLSM is used, the pipe cannot be perforated and all joints shall have gaskets.

- Beddingis required to establish line and grade and to provide firm, but not hard, pipe support. Compacted granular material over a flat trench foundation should be spread evenly and compacted uniformly to a firm, but not hard, support. Bedding materials may be Class I, II or III, except that AASHTO Section 30 limits the maximum particle size for bedding material to 1.25 in. (32 mm). Class IA materials (see Table 6-4 for definitions of soil classification) should not be used where groundwater flow is anticipated unless a geotextile trench wrap is used to prevent soil migration. Class III materials are suitable when moisture content is controlled.

  Approximately 4 in. (0.1 m) of bedding should be placed and compacted on the foundation to equalize load distributions along the invert of the pipe. The pipe can be placed on the bedding, then backfilled under the haunches. While not common, a shaped bedding that conforms to the outside of the pipe also can be used. Typically, the bedding equal to one-third the pipe O.D. should be loosely placed, while the remainder shall be compacted to a minimum 90% of maximum density per AASHTO T99 (see Figure 6-2).

Figure 6-2

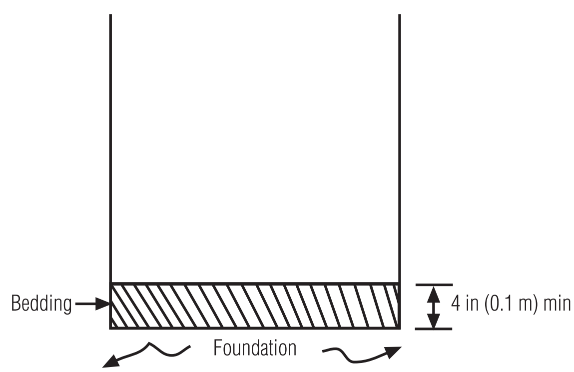

Figure 6-2: Location of Bedding Area of the Backfill Envelope

Figure 6-3

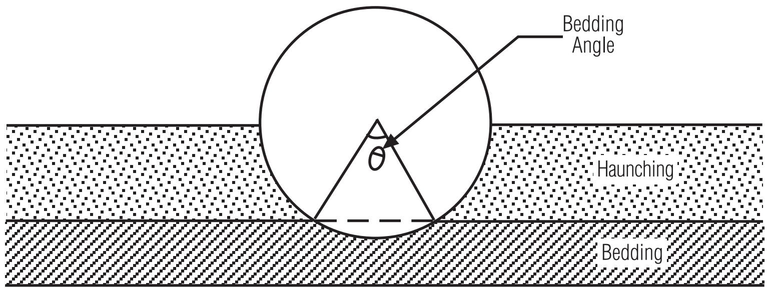

Figure 6-3: Bedding Angle

The bedding constant, (K), is a coefficient that accounts for the bedding support provided to the pipe. It is a function of the bedding angle. Very commonly, a value of 0.1 is assumed. Figure 6-3 and Table 6-3 provide additional details on appropriate values for alternative bedding constants.

Table 6-3

Bedding Constant Values

Bedding Angle, degrees	Bedding Constant
0	0.110
30	0.108
45	0.105
60	0.102
90	0.096
120	0.090
180	0.083

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The depth of the trench is dictated by the geography of the site and the pipe slope required. However, if an adequate foundation for the pipe is not available at the desired depth, additional excavation will be required. Rock outcroppings, very soft soils such as muck, and other similar materials do not provide proper support. They should be removed and replaced with suitable granular material. A soils engineer should be consulted for conditions of unyielding material or soft soils.

- The haunching area of the backfill envelope provides the majority of the resistance against soil and traffic loadings. The backfill material should be installed uniformly in layers, or lifts, on each side of the pipe. Larger, more angular backfill materials can usually be placed in thicker layers than materials with smaller, rounder particles. The backfill should be shoveled under the pipe, taking care to fill voids. If compaction is required, it should be conducted in such a way that the pipe alignment is not disturbed. Backfill construction should continue up to the pipe springline to complete the haunch area.

  Haunch materials may be Class I, II or III; they must be compacted to a minimum 90 percent standard Proctor. Voids and haunch areas are to be hand filled when Class IA materials are used.

- Initial backfill materials must provide adequate pipe support and protect the pipe from stones or cobbles in the final backfill. Initial backfill extends a minimum of 6 in. (150 mm) above the crown of the pipe. Class I, II, III and low plasticity Class IVA materials may be used. In practice, use of Class IVA fine-grained, inorganic, low to medium plasticity materials (ML and CL) is discouraged since compaction must take place at or near optimum moisture content to achieve the required density and thereby provide proper pipe support. Because these materials may not be suitable under high fills, surface wheel loads, or heavy construction equipment, they are used only under the direction of the responsible engineer. High plasticity clays and silts (Class IVB and all Class V materials) are not recommended for initial backfill. Class III materials are suitable only in dry trench conditions.

  Table 6-4 summarizes soil classifications. See ASTM D 2321 for complete details. (Also see AASHTO M 145 for details of that agency's soil classifications.)

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Table 6-4

Backfill Class and Quality

Pipe Embedment Material						E', psi (kPa) for Degree of Embedment Compaction				
ASTM D 2321*		ASTM D 2487		AASHTO M43	Min. Std. Proctor	Lift Placement	Dumped	Slightly < 85%	Moderate 85% - 95%	High > 95%
Class	Description	Notation	Description	Notation	Density (%)	Depth				
IA	Open-graded, clean manu-factured aggregates	N/A	Angular crushed stone or rock, crushed gravel, crushed slag; large voids with little or no fines	5 56	Dumped	18" (0.45 m)	1000 (6,900)	3000 (20,700)	3000 (20,700)	3000 (20,700)
IB	Dense-graded, clean manu-factured, processed aggregates	N/A	Angular crushed stone or other Class IA material and stone/sand mixtures; little or no fines							
II	Clean, coarse-grained soils	GW	Well-graded gravel, gravel/sand mixtures; little or no fines	57 6 67	85%	12" (0.30 m)	N/R	1000 (6,900)	2000 (13,800)	3000 (20,700)
		GP	Poorly graded gravel, gravel/sand mixtures; little or no fines							
		SW	Well-graded sands, gravelly sands; little or no fines							
		SP	Poorly graded sands, gravelly sands; little or no fines							
III	Coarse-grained soils with fines	GM	Silty gravels, gravel/sand/silt mixtures	Gravel and sand with <10% fines	90%	9" (0.20 m)	N/R	N/R	1000 (6,900)	2000 (13,800)
		GC	Clayey gravels, gravel/sand/clay mixtures							
		SM	Silty sands, sand/silt mixtures							
		SC	Clayey sands, sand/clay mixtures							
IVA**	Inorganic fine-grained soils	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, silts with slight plasticity				N/R	N/R	N/R	1000 (6,900)
		CL	Inorganic clays of low to medium plasticity; gravelly, sandy or silty clays; lean clays							
IVB	Inorganic fine-grained soils	MH	Inorganic silts, macaceous or diamaceous fine sandy or silty soils, elastic soils				N/R	N/R	N/R	N/R
		CH	Inorganic clays of high plasticity, fat clays							
V	Organic or highly organic soils	OL	Organic silts and organic silty clays of low plasticity				N/R	N/R	N/R	N/R
		OH	Organic clays of medium to high plasticity, organic silts							
		PT	Peat and other high organic soils							

N/R: Use not recommended by ASTM D 2321 for part of the backfill envelope.
*Refer to ASTM D 2321 for more complete soil descriptions.
**Use under the direction of a soils expert.

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Compaction Strategies and Equipment

As has been noted in earlier chapters, the performance of flexible pipe largely depends on the quality of the compacted fill in the embedment zone. The denser the fill, the more likely gravity loads of surcharge and live wheel loads will be attracted away from the pipe by the soil adjacent to the pipe. Furthermore, the denser the fill the lesser the tendency towards pipe ovality. Density is measured in kg/m^3, Mg/m^3 or in lb/ft^3.

A flexible pipe will perform in a stable and predictable manner as a pipe/soil composite structure when properly bedded throughout the embedment zone (Figure 6-1). After first connecting the pipe and checking for grade and alignment, haunching material at the underside of the pipe (5 o'clock and 7 o'clock locations) should be uniformly placed and tamped to the required compacted density before placing the remainder of the embedment materials. Properly compacted soils in these haunch locations can prevent pipe deformations. For all pipe materials, good construction practices require uniform compaction around the pipe to maintain grade and alignment.

All embedment materials should be worked to insure uniform compaction. Hand-held mechanical tampers are preferred between the pipe and trench wall. If necessary, vibratory equipment is preferred for the clean coarse-grained crushed stone, gravels and sands of Classes I and II. Consolidation of cohesionless material by watering (jetting or puddling) should only be used under controlled conditions and when approved by the engineer. Jumping jacks and walk-behind vibratory rollers, suitable for most classes of embedment and backfill materials, are generally used to provide the vibratory, kneading and impact force needed for soils of fine materials and high plasticity. For some non-free draining borderline Class II, Class III and Class IVA soils, ASTM D 2321 requires the moisture content be held 3% of optimum; AASHTO Section 30 requires a range of –3% to +2%. During placement and compaction of the embedment side fill, care must be taken to avoid elongation of the vertical diameter of the pipe in excess of the manufacturer's recommendation.

Engineers should establish the minimum embedment density based on an evaluation of specific project conditions. Do not assume that the minimum standard Proctor densities listed here are applicable for all projects. ASTM recommends a minimum of 85% standard Proctor for Class II and better soils, 90% for Class III soils and 95% for Class IVA soils. These recommendations are based on attaining an average modulus of soil reaction (E') of 1000 psi. AASHTO Section 30 recommends a minimum of 90% for all soils that meet their structural backfill requirements. At springline, the engineer or manufacturer may recommend a minimum allowable compaction of 95% standard Proctor density depending upon the specified acceptable limits of deflection. Compaction of the final backfill must satisfy loading, pavement and other requirements in addition to those of the pipe. Final backfill containing boulders or frozen debris should not be placed within 24 in. (600 mm) of the pipe.

When placing and compacting embedment soils, care should be taken to employ methods that will not disturb or damage the pipe. ASTM D 2321 does not permit compaction by hydrohammer unless first approved by the responsible engineer and unless the pipe/soil structure is protected by a minimum of 48 in. (1200 mm) of compacted backfill. Direct contact between the compaction equipment and the pipe should always be avoided. Sufficient backfill to prevent damage should be placed before using heavy compaction or construction equipment directly above the pipe. ASTM D 2321 requires the initial backfill be no less than 6 in. (150 mm) above the crown of the pipe. Amster Howard comments on this requirement and makes the following recommendations:

- Some specifications and standards for flexible pipe require that the compacted embedment continue up to a point 6 to 12 inches (150 to 300 mm) over the top of the pipe. For any compaction method, except saturation and vibration, this means that compaction equipment will be operating extremely close to the top portion of the pipe. When compacting soil at the sides of the pipe, the pipe is affected by the horizontal component of the impact force hitting the soil, which is much less than the vertical force. However, with the compaction equipment over the pipe, the vertical impact force is directed at the pipe and can cause impact damage that may not be readily apparent. Additionally, the pipe flexes as the impact is transmitted through the soil and does not provide a firm base to compact the soil against. Consequently, it is difficult to get high degrees of compaction (over 85% standard Proctor). When a standard or specification calls for 90 to 95% standard Proctor in this area over the pipe, attaining that degree of compaction is extremely rare for most types of flexible pipe.

- To reduce impact damage when the backfill soil is compacted (as under roads, landing strips, etc.), there should be at least 12 in. (300 mm) of cover over the pipe before using hand-held or walk behind compaction equipment, and at least 3 ft. (1 m) of cover before using ride-on equipment.

- These comments about compacting directly over the top of the pipe do not apply if the saturation and vibration method of compacting cohesionless, free-draining material is used. Similarly, filling up the trench with a material such as flowable fill does not create any of the (above) problems.

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Unless protected by sufficient cover, heavy construction equipment and other vehicles may damage the pipe/soil structure. Before allowing such traffic, the responsible engineer should establish a minimum depth of compacted backfill above the pipe. For embedment materials compacted to comply with the ASTM D 2321 densities noted previously, it is recommended to use the greater of one pipe diameter or 24 in. (600 mm) for Class IA and IB materials, and one pipe diameter or 36 in. (900 mm) for Class II, III and IVA materials.

Ground water and drainage flow during and after construction may cause migration of fines when coarse and open-graded material is placed adjacent to a finer material, often the trench wall. A degradation of the pipe/soil composite structure with unacceptable deflections can be the result. In some cases a stone filter or geotextile filter fabric along the fine soil boundary may be used to minimize such migration. For particular applications and related soil parameters, geotextile manufacturers can provide guidance on appropriate products.

System Inspection and Field Testing

Pipe installation, like any other engineered system, can benefit from frequent inspections to ensure that the pipe is installed according to specification. Timely inspections are required during construction to insure compliance. Performance inspections are required after completion of the work.

Attaining the specified degree of compaction is essential for the satisfactory performance of the pipe. Standard ASTM tests define the materials, processes and procedures for determining in-place field density tests by the following methods: sand cone, nuclear, sand replacement, water replacement, rubber balloon, drive cylinder and sleeve.

During construction, an experienced inspector can visually detect departures from proper alignment, grade, permissible deflections and unexpected deformations, as well as faulty joints, taps and other connections. Closed circuit television (CCTV) can be used to inspect small diameter pipes, sanitary sewer pipes and pipes which may present safety hazards. This procedure is very common in the sanitary sewer market. Problems should be remedied as soon as discovered. TV cameras should be capable of scanning the full extent of joints.

The engineer may require additional testing of the pipe's deflection performance. For pipes large enough for entry of personnel, diameter changes may be determined by direct measurement. For smaller diameter pipes, a mandrel may be pulled from manhole to manhole. As long as the deflection does not exceed the mandrel dimensions, it will go through the pipe. For this reason, mandrels are sometimes referred to as go/no go devices. Information obtained from mandrel tests can easily be misinterpreted, so a great deal of caution should be used when interpreting the findings. Mandrels may not be able to pass through pipe for a variety of reasons unrelated to deflection, such as blockage caused by debris, protrusion of fittings, joint misalignment, and grade changes. Manholes must be large enough to accept an assembled mandrel. It is extremely cumbersome to use mandrels to test pipe larger than 24 in. (600 mm). Visual inspection or CCTV is preferred for pipes larger than 24 in. (600 mm).

In the event of isolated areas of deflection greater than specification limits, re-rounding of the pipe with special equipment, without any excavation, should be considered. Long lengths of pipe with deflection levels greater than permitted are most likely due to compaction deficiencies. Material around the pipe may have to be excavated and replaced with proper material, properly compacted. A pipe that has not deflected to the point of reverse curvature can be re-rounded and reused.

To assure watertight joints in sanitary sewers and some storm sewers in environmentally sensitive areas, joints may need to be pressure tested after installation. Air or water can be used, although air is the most common because of safety considerations. Test requirements may vary from region to region, but most require the pipe to be pressurized to at least 3.5 psi (24.1 kPa) and held for a period of time based on the length and diameter of pipe. A small drop in pressure is usually permitted. See ASTM F 1417 and CAN/CSA B182.11 for more detailed information.

Summary of Pipeline Installation Considerations

The successful performance of buried pipelines of all materials is dependent on the interest, care and attention to detail on the part of the contractor. Installation contractors should have a basic understanding of the pipe/soil composites structure. This will enable the contractor to anticipate problems that may arise from poor construction practice not otherwise recognized as such. The following are the key areas of consideration:

- Proper excavation and preparation of the trench will inhibit unanticipated longitudinal and cross-sectional strains and stresses in the pipe. The buried pipe is sensitive to uniformity of the type and density of material of the trench bottom and sidewalls. Unexpected pockets or reaches of rocks, boulders or low-density soils encountered in the excavation should be reported. To avoid differential settlements being resisted by the pipe, shorter sections of pipe should bridge the transitions where different foundation soils meet.

- Standing or flowing water in the trench will soften the toe of the sidewall and increase the likelihood of unstable sidewalls and slopes. Ground water control should ensure a dry trench until the trench backfill is sufficient to prevent flotation of the pipe. Maintaining ground water control until backfilling is complete is preferred. To maintain the integrity of the in-situ soil in the vicinity of the trench, pumped water should be reasonably free of fines. Surface waters should be diverted away from the trench.

- Water flowing along the exterior of the pipe should be expected to erode compacted trench backfill and/or trench sidewall support for the pipe. In the case of free-draining granular trench backfill located in groundwater of any form, intermittent impervious trench dams (or plugs) of compacted cohesionless materials should be included to still the flowing water.

- Uniform compaction of embedment materials along the length of the pipe will distribute the reaction at the underside of the pipe and inhibit excessively large deflections of the pipe's cross-section. To assure proper final compacted soil densities, trench braces, shields and boxes must be removed prior to the completion of the compaction.

- Uniform support for the pipe is essential. Intermittent supports should not be used to establish the grade line. Clearance should be provided at protruding joints (bell and spigot, wrap-around joint couplings) of the pipe to prevent the likelihood of heavy and excessive "point" loads to these joints.

- Inspection helps insure that the pipe is installed according to project requirements. The installation integrity can usually be verified with a visual inspection, or CCTV in inaccessible situations. Deflection tests using mandrels are an alternative.

- Watertight, nonpressure systems may require pressure testing according to recognized procedures after installation to verify performance.

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Notes

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